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DIURNAL VARIATIONS IN THE FLUCTUATIONS OF ELECTRON DENSITY IN THE IONOSPHERE OF THE NORTHERN HEMISPHERE

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ABSTRACT: The paper makes an attempt to connect the appearance of the so-called F-scatter with large-scale fluctuations of the electron density in the F region of the ionosphere. The analysis of data obtained at several ionospheric stations made it possible to construct for the Northern Hemisphere a "map" of global variations of the P-index, which is proportional to the fluctuations of the electron density. Characteristic zones of fluctuations for magnetically quiet and magnetically disturbed days are revealed.

It is a known fact that the most important characteristics of the structure of ionospheric inhomogeneities, closely linked to fluctuations in the intensity of the radio emission from discrete sources and artificial earth satellites, are the deviations of the electron density ΔN of inhomogeneities from the average values of density N in a layer (so-called fluctuations of electron density) and the relative dispersion of electron concentration $\overline{\Delta N}/\overline{N}$. A detailed survey of articles devoted to investigation of electron density inhomogeneities [1] has shown that at the present time there are very few experimental data available on the fluctuations of electron density in the ionosphere, especially in the F2 layer. /77

On the other hand, we have emphasized in [2] that scattered reflections are an effective experimental basis for studying the inhomogeneous structure of the ionosphere. It was shown in [1, 3] that the so-called F-scattering and fluctuations in the intensity of radio emission from discrete sources are the general cause for the formation in the F-layer of the ionosphere of large-scale inhomogeneities in ionization, located over a broad range of altitudes. Each inhomogeneity has dimensions which are sufficient for formation of a single intense signal.

*Numbers in the margin indicate pagination in the foreign text.

In recent years, many papers (mostly foreign) have appeared which are devoted to the theoretical and experimental study of the phenomena of scattered reflections. A rather complete survey of the results is contained in [4-6]. It must be pointed out, however, that the overwhelming majority of the experimental studies have a purely phenomenological character, i.e., they are devoted primarily to a formal classification of the space-time distribution of the frequency of appearance and intensity of F-scattering. Thus, it was found that in the vicinity of the magnetic equator there is a belt of intense scattered reflections with a repetition frequency greater than 90%, and that in general, the area of geomagnetic latitudes from 20°N to 20°S the scattered reflections are a common occurrence in the nighttime ionosphere. On the other hand, however, in a narrow zone extending from 30 to 40° geomagnetic latitude, the appearance of scattered reflections is observed extremely rarely at any level of magnetic activity. Beginning at 40° geomagnetic latitude, the probability of occurrence of scattered reflections increases with latitude, reaching a maximum at latitudes greater than 60°. For geomagnetic latitudes below 70°, scattered reflections as detected by vertical pulse radiosoundings of the ionosphere are a typical nocturnal phenomenon. The maximum of probability of occurrence of scattered reflections is found, as a rule, in the hours around mi /78
midnight (before midnight for $\phi < 20°$ and after midnight at middle and high latitudes).

The statistical study of the probability of occurrence of scattered reflections [7] has shown that separate analyses must be conducted for magnetically quiet and magnetically disturbed conditions. A very important fact is that at all latitudes and at all seasons, regardless of the time of day and the conditions of geomagnetic activity, there is a tendency toward reduction of the probability of occurrence of scattered reflections with an increase in the electron concentration in the maximum of the layer [8-10].

B. Briggs [11], considering the intensity of the so-called scattering by frequencies, showed that seasonal and heliocyclic variations in this value are a secondary effect caused by corresponding variations in the critical frequencies. As far as the physical cause for "scattering by frequencies" is concerned, i.e., fluctuations in the electron density ΔN, an examination of random oscillations shows that these fluctuations do not have any regular seasonal variation.

Since the available data on global distribution of frequency of occurrence and intensity of F-scattering do not indicate the physical cause which produces them (ionospheric inhomogeneties), we felt that it would be very interesting to study the space-time distribution of fluctuations of electron density ΔN. The present paper is an initial attempt to study the diurnal variations ΔN on the scale of the Northern Hemisphere on the basis of data from vertical radio-soundings of the ionosphere conducted by a global network of stations during the International Geophysical Year.

The intensity of the F-scattering is determined by the value Δf, the range of frequencies near the critical frequency at which reflection from the layer occurs. Fluctuations of the electron density ΔN can be calculated if we know the critical frequency f_0F2 and the intensity of the scattering Δf. Since

$$N = 1{,}24 \cdot 10^4 f_0^2 \text{ electrons/cm}^3,$$

then

$$\Delta N = 2{,}48 \cdot 10^4 f_0 \Delta f \text{ electrons/cm}^3.$$

In our calculations, we use the data from two groups of stations: 17 stations in the Western Hemisphere, located within a narrow range of geographic longitudes (67-81.2°W) and in the range of geomagnetic latitudes 4.4°S-88°N (Table 1) and 18 stations located at middle latitudes in the Eastern Hemisphere ranging from longitudes of 0 to 26°E and lying in the range of geomagnetic latitudes from 46.6 to 70.2°N (Table 2).

Since we were unfortunately unable to have access to the records of the ionograms of the Worldwide network, we did not calculate the absolute values of ΔN but some value $p = f_0\Delta f$, proportional to ΔN. Both the values of f_0 and Δf were obtained from standard diurnal tables of f_0F2. The values of f_0 were rounded off with an accuracy of 0.1 MHz, while the values of Δf were determined on the basis of a four-point scale [13]. A scale of this type was selected because, in accordance with the international instructions [12], in the event of occurrence of F-scattering and its effect on the estimate of f_0F2, this fact is indicated in the tables with the aid of subscripts. If there was no F--scattering (only numerical values of f_0F2 are given in the tables), $\Delta f = 0$ on our scale. In those cases where the subscript f follows f_0F2 in the tables (indicating the presence of a small amount of scattering), $\Delta f = 1$. If the scattering was so great that the numerical value f_0F2 is accompanied not only by a following subscript F but is preceded by subscript (U, I, P), $\Delta f = 2$. Finally, with intense F-scattering, when it was not possible to calculate the critical frequency and the subscript F is placed in the table in place of the numerical value, $\Delta f = 3$.

TABLE 1. /79

No.	Station	Geographical latitude	Geographical longitude	Geomagnetic latitude
1.	Alert	82°33'N	62°35'W	85°49'N
2.	Thule	76 33	68 50	88 03
3.	Frobisher	63 45	68 34	75
4.	Fort Chimo	58.1°	68.4°	69.2
5.	Ottawa	45.4	79.9	57.0
6.	Fort Monmouth	40 15	74 01	51.7
7.	Bellevue	38 44	77 08	50.1
8.	Canaveral	28 4	80 6	40
9.	Bahama Islands	26 40	78 22	37.9'
10.	San Salvador	23 00	74°	33
11.	Ramea	18 30	67 12	30.0°
12.	Fort Randolph	09 23	79 53	20.6
13.	Bogota	4.5	79.2°	15.9
14.	Talara	4.6S	81.3	6.6
15.	Chimbote	9.1	78.6	2.1
16.	Chiclayo	6.8	79.8	4.4S
17.	Huancayo	12.0	75.3	0.6

TABLE 2

No.	Station	Geographical latitude	Geographical longitude	Geomagnetic latitude
1.	Kiruna	67°50'N	20°26'E	65.3°N
2.	Sodankyla	67 26	26.33	63 9
3.	Lulea	65 36	22 07	63.0
4.	Lyksele	64 37	18 40	62.7
5.	Rejkjavik	64 08	21 47	70°2'
6.	Nurmijarvi	60 30	24 39	57 9
7.	Uppsala	59 43	17 36	58 6
8.	Juliusruh	54 38	13 23	54 5
9.	Medzemin	52 10	21 12	50.7°
10.	Slough	51 29	00 34	54.3
11.	Lindau/Harz	51 39	10 39	52.4
12.	De Bilt	52 06	05 11	53.8
13.	Durk	50 06	04 36	52.0
14.	Prugonice	49 59	14 33	49.9
15.	Freiburg	48 03	07 35	49.4
16.	Budapest	47 26	19 11	46.6
17.	Graz	47 04	15 28	47.0
18.	Monte Cappelipo	44 33	08 57	45°8'

The system adopted for listing Δf is admittedly a rough one. However, the special comparison of ionograms contained in [13, 14], with standard diurnal tables for f_0F2, we were able to confirm that Δf = 1, 2, 3 corresponds to scattering when Δf = 0.25, 0.5, 0.75 MHz, respectively.

For the analysis, we used separately the data from five magnetically quiet and five magnetically disturbed days in December 1958 [14]. The period of the winter solstice is of considerable interest, since "scattering by frequencies" takes place most frequently in winter, especially at middle latitudes. For /80 each station, we have calculated the F values as medians for a given hour for

for the five days in question and the mean arithmetic values of Δf for the same hours. In the case where $\Delta f = 3$, the critical frequency for this hour was determined by interpolation on the f-graph for the hours in question. For the station at Thule, where $\Delta f = 3$ was observed in the majority of cases, the values for the critical frequencies for calculating P was selected on the basis of an average (median) diurnal pattern for f_0F2 for the entire month.

Hence, we calculated diurnal variations $P \sim \Delta N$ for each stage, the global distribution of these variations is shown in Figures 1 and 2. The averaging of P was performed within intervals of 6° of latitude.

Hours of the day

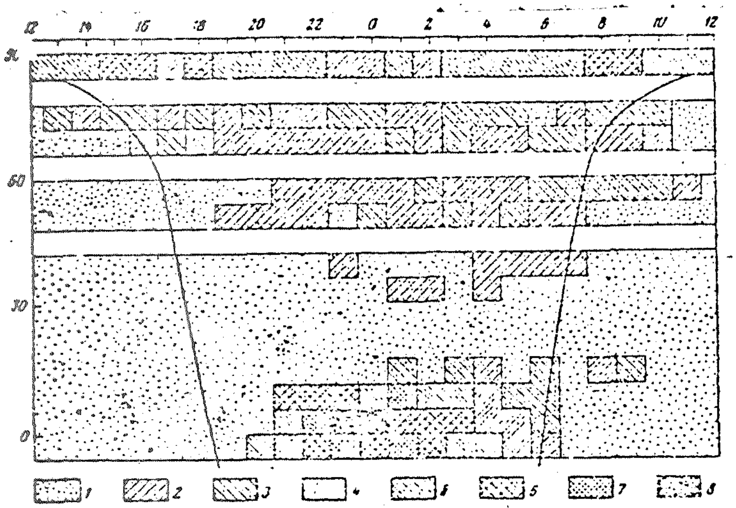

Figure 1. Diurnal Variations of ΔN (Western Hemisphere, Magnetically Quiet Days). 1, P = = 0; 2, P = 0 to 3.2; 3, P = 3.3 to 6.4; 4, P = 6.5 to 9.6; 6, P = 9.7 to 12.8; 6, P = = 12.9 to 16.0; 7, P = 16.1 to 19.2; 8, P > 19.2.

For convenience in study, the entire range of P values was subdivided into eight intervals. Their values are shown in Table 3 and in the caption to Figure 1.

An examination of the "charts" of variations in P made it possible for us to establish the zones of maximum and minimum values for fluctuations in electron density. During a magnetically quiet period (Figure 1) the zone $\Delta N = 0$ occupies a region extending from 18 to 30° latitude regardless of local times and nearly all of the sector illuminated by the sun (the sunrise and sunset lines are indicated on the charts for the winter solstice at the 250 km level [16]) at all latitudes. The exception is the hours before noon at latitudes of 54 to 78° and one hour after sunrise in the zone from 6°S to 18°N. High values of ΔN were observed in the equatorial ionosphere (0 to 18°) during the nighttime hours from 2100 to 0600 hours. The maximum values were found only during two hours near midnight in a narrow range of latitudes from 0 to 6°. The increase in ΔN values takes place abruptly, beginning at 2100 hours, /81 while the decline is gradual until 0600 hours.

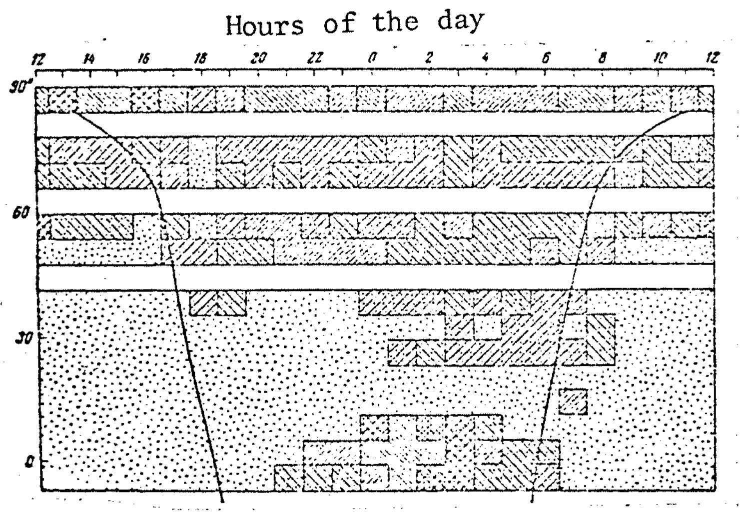

Figure 2. Diurnal Variations of ΔN (Western Hemisphere, Magnetically Disturbed Days). See Figure 1 for symbols.

At middle latitudes during the nighttime hours, ΔN is significantly less than at the equator, while in the region of latitudes from 30 to 42° the nonzero values of ΔN are observed only in scattered zones during the midnight and predawn hours. In the zone of latitudes from 48 to 60°, the ΔN values increase somewhat ($P \leqslant 6.4$). During the period from 2000 to 1200 hours, ΔN shows only slight variations.

In the auroral zone (66 to 78°), the ionosphere is inhomogeneous practically at all hours ($P \leqslant 9.6$) with the exception of several hours near noon when $\Delta N = 0$. At the polar cap ΔN reaches a very high value ($9.6 < P \leqslant 16.0$) so that we can consider that the regular diurnal variation of ΔN is absent. It should be mentioned that the transition from the zone of increased values of ΔN near the equator to the "zero" zone occurs very sharply, while the increase in ΔN from the zero zone toward higher latitudes occurs smoothly.

TABLE 3.

Interval	1	2	3	4	5	6	7	8
P	0	0—3,2	3,3—6,4	6,5—9,6	9,7—12,8	12,9—16,0	16,1—19,2	>19,2

The global distribution of diurnal variations of ΔN in the magnetically disturbed period (Figure 2) has a somewhat different appearance. Thus, in the equatorial regions ΔN decreases sharply in the hours before midnight; rarely, there are instances of significant variations of ΔN during the daytime, and in the interval of latitudes from 12 to 24°, $\Delta N = 0$ at practically all hours. It is interesting to note that at latitudes of 12 to 18°, during both magnetically quiet and magnetically disturbed periods, there is a brief "peak" from 0700 to 0900 hours local time against a zero background.

The distribution of ΔN in the range of latitudes from 48 to 60° differs considerably from that discussed above. The increase in ΔN during the nighttime hours and the appearance of intense inhomogeneity during the daytime is evident. As far as the auroral zones and the regions located in latitudes of 84 to 90° are concerned, it is our opinion that the differences found here in the distribution of ΔN in the magnetically quiet and magnetically disturbed periods are insignificant. We might merely mention the tendency toward an increase in inhomogeneity during the daytime that is observed during magnetic disturbances. A study of the variations of ΔN in the Eastern Hemisphere (the range of latitudes from 46 to 70°) makes it possible to notice the same features which were observed in the Western Hemisphere (see Figures 1 and 2).

Since, as we have mentioned above, there is a dependence between the frequency of occurrence of F-scattering and the concentrations of electrons in the maximum of the layer [9, 10], it was interesting to compare the charts for /82
nighttime hours showing ΔN with similar charts for critical frequencies. One of these charts is shown in Figure 3. A comparison of charts for corresponding periods will show a pronounced inverse relationship between ΔN and f_0F2, at high and middle latitudes in any case, i.e., precisely where the diurnal variations of ΔN are less regular. In the equatorial region, such a tendency is found, but is much less pronounced.

Several investigators [6, 11] have expressed the opinion that the absence of diffuse reflections in the night in regions of critical frequencies on ionograms does not mean that inhomogeneities are completely absent but merely indicates the shift of inhomogeneities above the maximum of the F2 layer.

At this time, then, in those ionograms which were recorded with vertical radio sounding of the ionosphere "upward", using ionospheric stations mounted aboard artificial earth satellites, intense scattered reflections would be observed in the frequency range below critical levels. In [17], results were published concerning the study of F-scattering with the aid of the Canadian satellite "Alouette" with an ionosonde on board. Figure 4 shows the global distribution of the diurnal variations of the frequency of appearance of low-frequency F-scattering, recorded on the ionograms from the satellites (taken from [17]). The data refer to 14 November 1962, a magnetically quiet day. The comparison of Figures 1 and 4 will show that during the night, in the region of latitudes up to 30° at $\Delta N = 0$, ground data indicate intense inhomogeneities above the maximum of the F2 layer. It is interesting to note that the "peak" of inhomogeneity in the interval from 12 to 18° at approximately 0700 to 0900 hours also appears in the data from the satellite. Another striking fact is that the peak of the frequency of occurrence of inhomogeneities following sunrise near the equator (Figure 4) coincides with the moment of the abrupt transition to $\Delta N = 0$ in the same region on the basis of ground observations (see Figure 1).

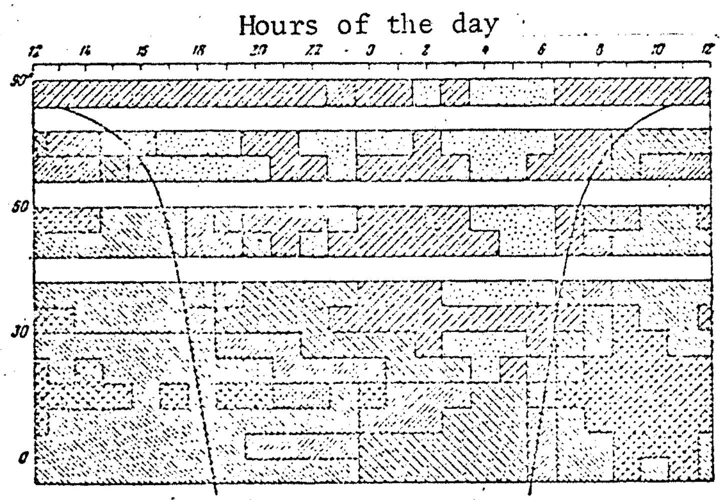

Figure 3. Diurnal Variations of f_0F2 (Western Hemisphere, Magnetically Quiet Days). See Figure 1 for symbols.

Hence, we can reach the following conclusions on the basis of this work:

1. The plotting of the global distribution of diurnal variations of ΔN, calculated on the basis of data regarding scattered reflections in the F layer, makes it possible to obtain more detailed information than study of the probability characteristics of F-scattering.

2. The degree of inhomogeneity of the ionosphere in the equatorial and /83
middle latitudes is largely dependent on the magnetic activity, while it is

only slightly dependent in the auroral zone and at the polar cap.

3. Fluctuations in electron density undergo regular diurnal variations only at low and middle latitudes. At high latitudes ΔN remains rather high, changing only slightly from day to night.

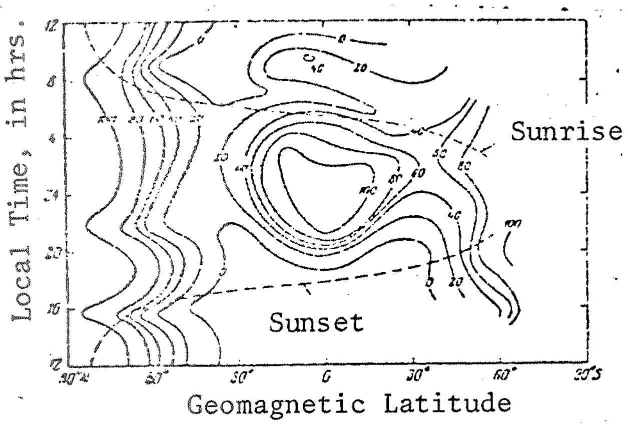

Figure 4. Diurnal Variations of the Probability (in %) of Occurrence of F-Scattering in Ionograms ("Alouette" Satellite, 14 November 1958).

4. In magnetically excited periods, the zone of intense inhomogeneities shifts considerably toward the equator relative to the magnetically quiet periods. This fact is in good agreement with data regarding movements of large-scale inhomogeneities in the F-layer of the ionosphere and the so-called moving ionospheric disturbances.

5. A comparison of the data obtained with the results of sounding of the ionosphere "upward" speaks in favor of the assumption of the movement of inhomogeneities causing F-scattering above the maximum of the F2 layer during periods when the scattered reflections are not observed in ground-recorded ionograms.

6. Significant progress in following inhomogeneities producing scattered reflection, fading of radio sources and signals from artificial earth satellites can be achieved by constructing detailed "charts", similar to those described, on the basis of a record of the ionograms from the worldwide network of stations and comparing these charts with synchronous data on scattered reflections obtained with the aid of artificial earth satellites.

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